# Bidirectional Transmission in Colourless WDM-PON based on Injection-Locked Fabry-Perot Laser at 2.5 Gbit/s using Low-Cost Seeding Source

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**Abstract** *Error-free transmission over 20km of 8-channels for both downstream and upstream in colourless WDM-PON based on injection-locked Fabry-Perot laser is experimentally demonstrated at 2.5Gbit/s, using a single quantum dash mode-locked laser as multi-wavelength seeding source.*

## Introduction

To meet the bandwidth demand of next generation optical access network to deliver broadband services, wavelength division multiplexed passive optical network (WDM-PON) is considered as the ultimate solution thanks to its very high capacity [1]. Many proposals for WDM-PON using low-cost optical transmitters have been made during last years. These solutions are typically based on spectrum-sliced seeding for injection-locked Fabry-Perot lasers (IL-FP) [2] or reflective SOA [3]. But their performance is limited to 1.25 Gbit/s due to high intensity noise of spectrum-sliced signal (around -105 dBc/Hz) even if the bandwidths of IL-FP and RSOA are higher.

To break this limitation while maintaining cost-effectiveness, we propose in this paper a new optical transmitter solution for colourless WDM-PON using a polarization-insensitive IL-FP laser directly modulated at 2.5 Gbit/s and a single quantum dash passively mode-locked Fabry-Perot laser (QD-MLL) as a low-noise, coherent multi-wavelength seeding source for injection-locking. The feasibility of such solution in a WDM-PON architecture is evaluated for both downstream and upstream transmission of 8 channels over 20 km SMF fibre with 42.7 GHz channel spacing in the C-band.

## Proposed colourless transmitter solution

QD-MLLs are attractive because they present very low-noise, high thermal stability and broad gain spectrum [4]. Given such advantages, we propose to combine the comb generation in a QD-MLL with a tunable array waveguide grating (AWG) in WDM-PON system to provide a multi-wavelength coherent source, instead of using N single mode lasers, to injection-lock the FP lasers used as colourless transmitters. The tunable AWG is aligned so that its channels coincide with the modes of QD-MLL. Fig. 1a presents a quasi-flat optical spectrum of QD-MLL over 10nm in C-band. This QD-MLL has a free spectral range of 42.7 GHz. Eight modes ranging from 1556.65 nm to 1559.07 nm are chosen for downstream and eight other ones ranging from 1562.18 nm to 1564.62 nm for upstream. The two wavelength bands for downstream and upstream are separated by 8 channels so that the cyclic AWG can be commonly used for 2 directions for practical implementation (i.e. two different wavelengths of downstream and upstream are routed into a same port of AWG). Fig. 1b presents optical spectrum of one mode of QD-MLL selected by AWG and one of IL-FP using this mode. Single mode operation of IL-FP with a side mode suppression ratio (SMSR) higher than 30 dB is achieved. The FP laser in this experiment is fabricated using a polarization-insensitive gain material as the gain section and a strained InGaAs material in the second section to compensate for birefringence. Therefore, this FP laser operates in both TE and TM modes, and furthermore, the optical spectra of two mode lines TE and TM are superimposed. Consequently, the injection-locking of this FP laser does not depend on the polarization state of the injected signal [5]. When the second section is polarized by a current higher than a threshold value (around 10 mA), a quasi-superimposition of the two mode lines is obtained in the range of 1545 nm to 1565 nm. Fig. 1c presents the wavelength allocation of 8 channels of downstream and upstream signals at the common port of AWG (in fig. 3 and fig. 5). The SMSR of each channel is around 40 dB thanks to the re-slicing of IL-FP by AWG.

The measurements of relative intensity noise (RIN) are presented in fig. 2. The QD-MLL presents very low RIN (< -150 dBc/Hz). However, 1 selected mode of QD-MLL has high RIN level, mainly in low frequency because of mode partition noise. Nevertheless, we observe an important noise reduction of IL-FP (with -3 dBm injection in this case) thanks to injection-locking mechanism. These RIN measurements are confirmed by the eye diagrams of free-running FP LD and IL-FP on the right.

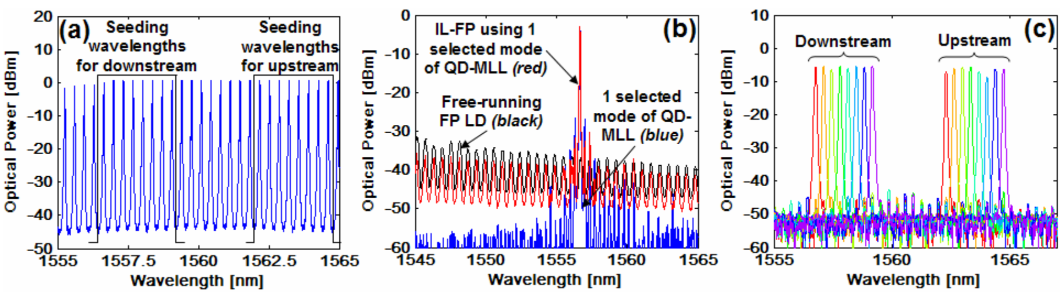


**Fig. 1:** Optical spectra of: QD-MLL *(a)*, injection-locking of FP laser using 1 selected mode of QD-MLL *(b)* and 8 WDM channels of downstream and upstream signals *(c)*

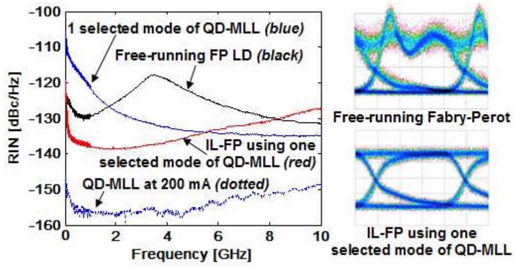


**Fig. 2:** Relative intensity noise

**Downstream transmission experiment and results**

Fig. 3 presents the experimental setup for downstream transmission. At Central Office, a QD-MLL amplified by a high power EDFA (23 dBm) is serving as a seeding source for both downstream and upstream. As mentioned above, 8 channels of tunable AWGs must be aligned with the 8 modes of QD-MLL. The IL-FP is biased at 75 mA on the gain section and then directly modulated by a 2Vpp amplitude $2^7$-1 PRBS at 2.5 Gbit/s. The bias current of the second section is varied up to 100 mA so that an optimal detuning for which a maximum injection-locking efficiency is obtained. The optical power injected into the FP laser is around -2 dBm and the IL-FP has 3 dBm output power. The optical signal is detected by a commercial PIN receiver at 2.5 Gbit/s at ONU. The measured optical budget of this system is nearly 20 dB.

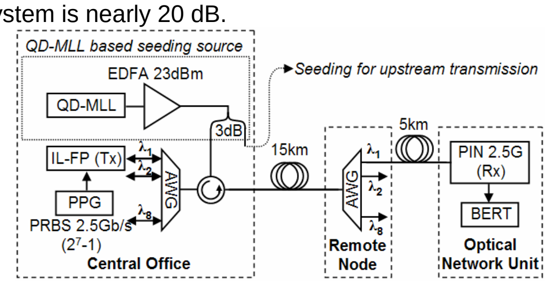


**Fig. 3:** Experimental setup for downstream transmission

The BER measurements versus received power for downstream transmission are shown in fig. 4. Error-free transmission is achieved and a negligible power penalty (~0.25 dB) at $10^{-9}$ is obtained after 20 km transmission. The receiver sensitivity at $10^{-9}$ covers from -21.5 dBm to -21 dBm.

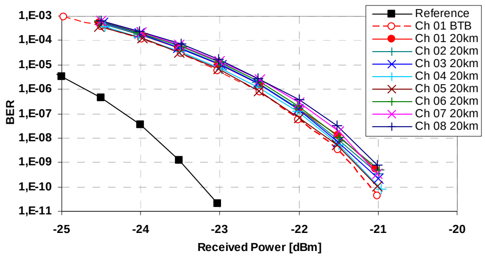


**Fig. 4:** Performance results of downstream transmission

This sensitivity is compared with the reference one, which is measured using low-noise tunable external cavity laser and LiNbO3 modulator at 2.5 Gbit/s.

**Upstream transmission experiment and results**

Fig. 5 presents the experimental setup for upstream transmission. For upstream transmission, the Rayleigh backscattering is the main limitation in WDM-PON with centralized light source [6]. To avoid this impairment without significant increasing of system complexity, we propose, in this experiment, an architecture with dual-fibre between Central Office and Remote Node: one fibre for seeding signal and one for upstream signal. In this case, Rayleigh backscattering is only generated over 5 km of drop fibre, which is very weak. Because of the attenuation due to propagation over 20 km, the injected power into the FP laser is only about -7 dBm in this case. However, the injection-locking regime is always maintained.

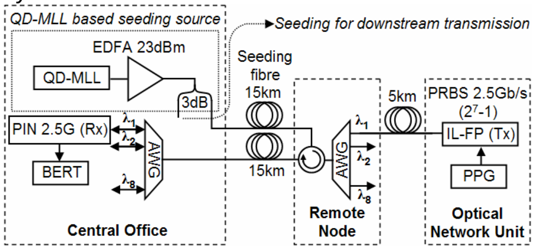


**Fig. 5:** Experimental setup for upstream transmission

Fig. 6 shows the BER measurements versus received power for upstream transmission. Error-free transmission is achieved for all channels and a power penalty of 1.2 dB is found after 20 km transmission at $10^{-9}$. This higher penalty compared to downstream transmission is due to the lower efficiency of noise reduction with lower optical power injection and to the small noise contribution of Rayleigh backscattering generated over 5 km of drop fibre. The receiver sensitivity ranging from -19.5 dBm to -20.5 dBm is obtained at $10^{-9}$.

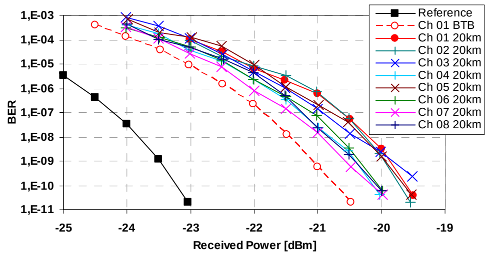


**Fig. 6:** Performance results of upstream transmission

**Conclusions**

We have experimentally demonstrated the feasibility of using a single QD-MLL as a low-noise, coherent multi-wavelength seeding source for colourless transmitters based on polarization insensitive IL-FP in WDM-PON system for both downstream and upstream transmission. Error-free transmission at 2.5 Gbit/s with a low power penalty was achieved over 20 km of SMF for 8 channels with 42.7 GHz channel spacing in C-band. This novel concept based on QD-MLL is very promising for the future WDM-PON system as a cost-effective transmitter solution.


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